

IONIZATION IN CLOSED VESSELS

BY

WILLIAM W. STRONG

DISSERTATION

SUBMITTED TO THE BOARD OF UNIVERSITY STUDIES OF THE JOHNS
HOPKINS UNIVERSITY, IN CONFORMITY WITH THE REQUIREMENTS
FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

BALTIMORE

1908

IONIZATION IN CLOSED VESSELS

BY

WILLIAM W. STRONG

DISSERTATION

SUBMITTED TO THE BOARD OF UNIVERSITY STUDIES OF THE JOHNS
HOPKINS UNIVERSITY, IN CONFORMITY WITH THE REQUIREMENTS
FOR THE DEGREE OF DOCTOR OF PHILOSOPHY



BALTIMORE

1908

IONIZATION IN CLOSED VESSELS.

BY W. W. STRONG.

INTRODUCTION.

GEITEL¹ and C. T. R. Wilson² were the first to show that gases in closed vessels have the power to conduct electricity to a slight extent and hence are slightly ionized.

This ionization may be due to one or more of four causes, namely: (1) a spontaneous ionization of the enclosed gas itself; (2) the presence of radioactive substances in the gas or in the walls of the vessel; (3) a penetrating radiation (and secondary radiations which may be excited by this) coming from outside the vessel; (4) intrinsic radiations coming from the walls of the vessel and characteristic of the material forming the walls.

At the present time it is believed that the spontaneous ionization of the gas is very small if it exists at all. Radioactive substances have, however, been found in the air, in gases dissolved in the waters of springs, in various minerals, rocks and soils. The metals, especially lead, are known to contain minute traces of radioactive impurities. The surfaces of bodies exposed to the air are found to gather a layer of radioactive substances upon their surfaces. A penetrating radiation³ resembling the γ radiation has been discovered. The work of Campbell,⁴ Wood and others indicate that each of the various metals emits radiations peculiar to itself.

When this investigation was commenced it was considered by Eve⁵ and others that it was probable that a large part of the penetrating radiation was due to radioactive products in the ground, and was constant in amount. If then any cause produced a change in the ionization within a closed vessel, this change should not be diffi-

¹ Phys. Zeit., 2, 116, 1900.

² Proc. Camb. Phil. Soc., II., 52, 1900.

³ McClennan and Burton, PHYS. REV., No. 3, 1903. Cooke, Phil. Mag., p. 403, 1903.

⁴ Phil. Mag., p. 206, 1906.

⁵ Phil. Mag., p. 189, 1906.

cult to detect. It was thought that if an electroscope was lined with iron (French rolled steel was used in one case) and placed in a magnetic field, then this magnetic field might induce powerful enough fields about the iron atoms to modify their natural radioactivity if they possessed any. Also if the enclosed gas was magnetic, the magnetic field would slightly change the amount of energy necessary to ionize the molecules.¹ It was found that the ionization in an electroscope as measured by the rate of leak was less in a magnetic field and that this effect was larger when the field was first applied. But it was found that the variation of the rate of leak of the electroscope was so large as to make the effect of the magnetic field questionable. In order to continue the work on the effect of a magnetic field it became necessary to study the variations of the ionization in closed vessels, its cause and how it can be kept constant.

I. DESCRIPTION OF THE ELECTROSCOPES.

One type of electroscope that the writer is using is the Wilson form described in Rutherford's *Radioactivity* (p. 86). The other kind consists of a charged wire bent into the form of an arc and along which an earthed gold leaf moves as the potential of the wire is changed. This form of electroscope will be described shortly.

Most of the Wilson electroscopes were made of glass vessels 12.5 cm. high and 10 cm. in diameter, having a volume of one liter. These were washed with water and acids and lined either upon the inside or outside with metal foil. One that has been used a great deal was lined with aluminium foil upon the inside. Windows were made in the aluminium and circular scales were fastened upon the inside, and upon opposite sides of the gold leaf. By reading the same number on each scale, parallax was avoided. Sulphur was used as an insulator in all cases. Before putting sulphur upon a metallic surface, the metal was coated with pieces of hard rubber. These pieces of hard rubber were stuck on while they were hot and adhered to the metal very well. The sulphur was then flowed about the pieces of hard rubber.

The gold leaf was cut with the sharp edge of a piece of cane, the

¹ Langevin, *Jour. de Phys.*, Oct., 1905.

leaf having previously been spread upon a soft, smooth cushion of chamois leather kindly given me by a gold-beater. This method is a quick and easy one. Strips 3 or 4 cm. long and .2 or .3 mm. wide can easily be cut. By pressing the ends together, strips as long as one wishes can be made.

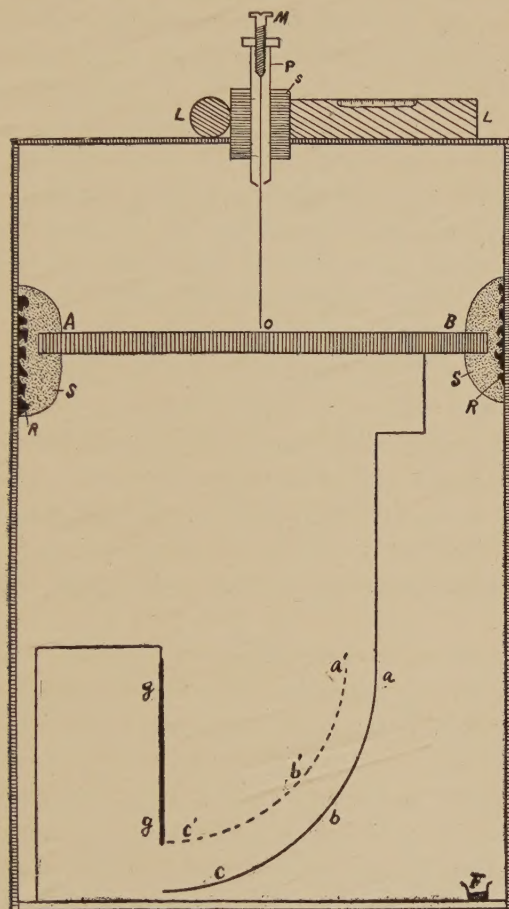


Fig. 1.

The accompanying figure shows the cross-section of a curved electrode electroscope briefly described in *Science*, p. 522, April 5, 1907. The dimensions of the electroscope are $12.9 \times 20.1 \times 10.1$ cm. *R* shows some rough pieces of hard rubber upon which the sulphur *S* was flowed. *AB* is a soft iron bar, and *abc* is a copper wire.

AB is 11.7 cm. long and .528 cm. in diameter; abc was 16 cm. long and .060 cm. in diameter. The gold leaf was 6 cm. long, and is represented by gg . The inside of the electroscope is lined with sheet iron, the surface of which was polished with emery cloth.

AB is charged by means of a screw M and wire MO . A small spark gap at O can be made larger or smaller according as M is screwed up or down. When the spark gap is of convenient length sealing wax can be flowed about M and the electroscope will then be air-tight. P is a glass tube and Q a rubber plug. LL are spirit levels. The gold leaf gg is always earthed. As the potential of AB abc is raised, the gold leaf rises along the path $c'b'a'$. By properly curving cba , the electroscope may be made very sensitive. There are two small windows to the electroscope and cba is placed close enough to the one window so that the gold leaf will be in the focus of the reading micrometer microscope. Upon the window are placed threads so that the various parts of the path of the gold leaf along $c'b'a'$ are marked. In most of the work a path of about .5 cm. length was used. For this length of path the motion of the gold leaf was almost linear so that the micrometer eyepiece thread when once set parallel to the edge of the gold leaf, remained so over a considerable portion of the path. Readings were taken by making the eyepiece thread tangent to a given projection on the edge of the gold leaf.

The advantages of the curved electrode electroscope are: (1) the gold leaf always turns so that its plane is parallel to the plane of the curved electrode. As the curved electrode is made parallel to the window, all parts of the gold leaf will be in the perfect focus of the reading microscope at the same time if this is perpendicular to the window; (2) as the gold leaf is earthed and the curved electrode may be made firm, the gold leaf may be placed as near the window as one likes and short focus reading microscopes may be used; (3) the electroscope is always horizontal and may easily be set up; (4) the sensibility may be made very large if the curved electrode is properly curved and has a small capacity; (5) the calibration curve is a straight line over a considerable portion of the path if the electrode is bent into the form of a circular arc. The disadvantages are that the instrument is a gravity instrument and the gold leaf is subject to air currents and radiometric effects.

II. CONSTANCY OF THE RATE OF LEAK OF SCREENED ELECTROSCOPES.

It was found during the course of the work that the rate of leak in closed vessels was much more constant when the external penetrating radiation was cut off by lead and iron screens.¹ A combination of lead and iron screens was used in order to be certain of cutting off both kinds of the radium γ radiations, as described by Kleeman.²

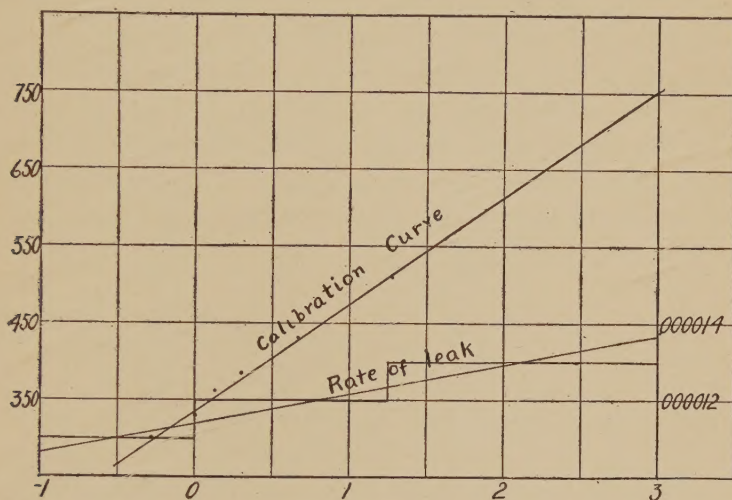


Fig. 2.

As an example showing the constancy of the rate of leak when the electroscopes is screened, some readings made with the aluminium-lined liter electroscopes will be given. This is one of the electroscopes previously described. Fig. 2 gives the voltage of the gold leaf for given divergences in scale divisions. It also gives the rate of leak in scale divisions per second when the electroscopes was surrounded with lead and iron screens 6 to 8 cm. in thickness. This rate of leak was found to be entirely independent of external conditions and was constant for any part of the scale. The rate of leak was never found to be less than the values given in Fig. 2 under any conditions of screening. It therefore seems to be very proba-

¹ Science, July 12, 1907.

² Phil. Mag., Nov., 1907.

ble that this rate of leak is due to radiations from the walls of the electroscope. All other variations in the rate of leak must be due to external causes. If the rate of leak for any part of the scale under given conditions is divided by the rate of leak for the same part of the scale as given by Fig. 2, the result will give the number of times the rate of leak is greater than .000010 scale divisions per second.

The capacity of the electrode and gold leaf was approximately .85 cm. The rate of leak of the screened electroscope between the values 0 and 3 on the scale corresponds to the generation of 7 ions per cu. cm. per second using the value of $6.5 (10)^{-10}$ electrostatic units for the charge on an ion. One can thus reduce all readings to ions generated per cu. cm. per second. In the fourth column of the following tables, .000010 is equivalent to the current that would be carried when 7 ions are formed per c.c. per second, there being a saturation current.

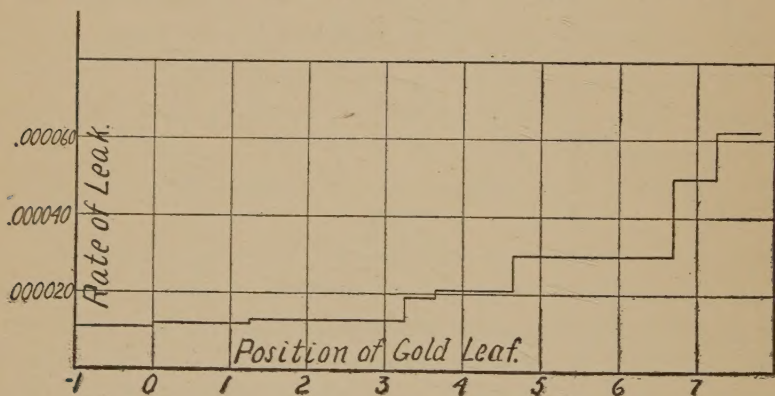


Fig 3

Fig. 3 was taken January, 1908. The rate of leak was also found in a cistern of rain water for the same electroscope. The cistern was dug in the ground and was large enough so that there was at least four feet of water in all directions about the electroscope. The electroscope was suspended vertically all the time. In the readings, the value .000010 for the rate of leak in scale divisions per second indicates that all the penetrating radiation has been screened off. With the exception of the reading made on Sep-

tember 11, it is to be noted that these readings are almost exactly the same as those made with the electroscope enclosed in lead screens.

TABLE I.
Electroscope in Cistern.

I.	II.	III.	IV.
Local Mean Time.	Position of Gold Leaf.	Leak in Scale Divisions Per Second.	III. Divided by the Sensibility.
Sept. 10, 1907.			
10 hrs. 4' A. M.	7.15	.0	
3 " 41' P. M.	6.20	.000035	.0000103
Sept. 11, 1907.			
6 hrs. 47' A. M.	4.57	.000037	.0000130
1 " 5' P. M.	4.07	.000022	.0000105
6 " 15' P. M.	3.65	.000029	.0000107
Sept. 12, 1907.			
7 hrs. 1' A. M.	2.78	.000019	.0000118
Sept. 13, 1907.			
9 hrs. 2' A. M.	1.65	.000012	.0000098
5 " 28' P. M.	1.25	.000012	.0000101
Sept. 14, 1907.			
8 hrs. 36' A. M.	.60	.000012	.0000105
		Average.....	.0000106

During the night of September 10 there was a heavy thunder-storm and a considerable amount of fresh rain water ran into the cistern. As rain is known to carry down radioactive products mostly derived from radium, it is quite likely that these products caused the increased rate of leak. On account of the short period of these products their effect soon vanishes. It is interesting to note that this method might give an approximate result for the amount of radium in the air. Knowing the height from which the rain fell, and supposing all the active deposit to be carried down, one could calculate the volume of air from which the active deposit was formed. From the increased rate of leak one could calculate the amount of radium products in the rain water and all the data necessary would be known.

III. VARIATION OF THE RATE OF LEAK OF UNSCREENED ELECTROSCOPES.

When electroscopes are not screened the rate of leak is subject to wide variations. For small metallic electroscopes these vari-

ations are not large, but for large electroscopes the variations are much greater. One of the most marked examples of these variations will now be given.

During the summer of 1907 the aluminium-lined electroscope was used at the writer's home in the country one mile southeast of Mechanicsburg, Pa. The ground is almost entirely under cultivation and is of Trenton limestone formation similar to that analyzed by Eve.¹ The electroscope was placed near a large window, the curtain of which was left open so as to make the room light enough to read the electroscope. The room was kept closed so that the temperature did not vary more than 1° or 2° C. during the day. Following are some typical examples.

These examples were all taken at the same place. It is seen that the rate of leak becomes very large during the middle part of the day reaching a maximum at 11 A. M. This change of the rate of leak is either due to an increase of conduction over the sulphur insulation or to an increase of ionization due to an external radiation. As the temperature of the room did not vary greatly and as it was also kept rather dark one would not see why the insulation should be decreased during the day. Only diffused daylight fell upon the aluminium electroscope. It is quite probable, however, that the rate of leak does not vary directly as the penetrating radiation. Neither is the large value of the rate of leak during the middle of the day due to a penetrating γ -like radiation entirely, as will be shown later.

An electroscope of the curved electrode form was made of glass walls wrapped with fine copper wire. The copper wire was earthed. The rate of leak was found for this electroscope when placed in a darkened room and also when a beam of sunlight was sent through the vessel. Very large movements of the gold leaf were produced of course by the sunlight but the readings were taken an hour or more after the sunlight was removed. The sunlight did not greatly increase the rate of leak except when it was directed upon the sulphur insulation. A more careful investigation of this is to be made.

The enormous daily variation shown above may bear some relation to the increased ionization found in the open air during the day in

¹ Phil. Mag., Aug., 1907.

TABLE II.
Electroscope in the Country.

I.	II.	III.	IV.
Local Mean Time.	Position of Gold Leaf.	Leak in Scale Divisions per Second.	III. Divided by the Sensibility.
June 29, 1907.			
3 hrs. 29' P. M.	4.85	.000104	.000045
5 " 15' P. M.	4.19	.000025	.000012
7 " 23' P. M.	4.00		
June 30, 1907.			
6 hrs. 49' A. M.	2.98	.000025	.000012
10 " 26' A. M.	1.59	.000107	.000082
1 " 31' P. M.	.12	.000132	.000100
3 " 46' P. M.	-.57	.000085	.000077
July 30, 1907.			
5 hrs. 48' P. M.	2.90		
July 31, 1907.			
6 hrs. 6' A. M.	.87	.000045	.000034
12 " 47' P. M.	4.05		
5 " 27' P. M.	.10	.000253	.000169
7 " 13' P. M.	-.20	.000047	.000043
7 " 15' P. M.	6.65		
Aug. 1, 1907.			
7 hrs. 12' A. M.	3.80	.000066	.000024
Aug. 2, 1907.			
7 hrs. 5' P. M.	4.77		
Aug. 3, 1907.			
7 hrs. 28' A. M.	.54	.000095	.000060
6 " 20' P. M.	5.40		
Aug. 4, 1907.			
7 hrs. 28' A. M.	.20	.000110	.000066
10 " 51' A. M.	3.90		
1 " 41' P. M.	-1.00	.000480	.000359
1 " 42' P. M.	4.40		
7 " 57' P. M.	-.60	.000222	.000154
7 " 58' P. M.	5.40		
Aug. 5, 1907.			
7 hrs. 50' A. M.	.95	.000104	.000055
Sept. 2, 1907.			
2 hrs. 4' P. M.	3.97		
5 " 49' P. M.	1.97	.000148	.000095
8 " 53' P. M.	1.78	.000017	.000013
Sept. 3, 1907.			
3 hrs. 6' A. M.	1.10	.000033	.000025
7 " A. M.	.80	.000021	.000018
10 " 14' A. M.	.14	.000057	.000050
11 " 33' A. M.	-.57	.000171	.000155

TABLE II.—*Continued.**Electroscope in the Country.*

I.	II.	III.	IV.
Local Mean Time.	Position of Gold Leaf.	Leak in Scale Divisions per Second.	III. Divided by the Sensibility.
Sept. 3, 1907.			
12 hrs. 46' P. M.	4.70	.000239	.000150
5 " 25' P. M.	.70	.000050	.000042
7 " 5' P. M.	.40		
8 " 24' P. M.	7.70	.000057	.000010
11 " 6' P. M.	7.15		
Sept. 4, 1907.			
6 hrs. 51' A. M.	5.56	.000057	.000015
11 " 10' P. M.	5.80		
Sept. 5, 1907.			
6 hrs. 55' P. M.	4.27	.000055	.000020
9 " 37' P. M.	.50	.000388	.000277
Dec. 22, 1907.			
6 hrs. 57' A. M.	1.25	.000016	.000012
8 " 52' A. M.	1.08	.000024	.000020
10 " 8' A. M.	.80	.000061	.000050
12 " 12' P. M.	.30	.000067	.000056
1 " 43' P. M.	6.40	.000236	.000078
2 " 42' P. M.	5.55	.000150	.000050
3 " 54' P. M.	4.90	.000062	.000023
5 " 23' P. M.	4.57	.000030	.000013
5 " 41' P. M.	4.43	.000040	.000019
9 " 21' P. M.	4.05		
Dec. 23, 1907.			
6 hrs. 31' A. M.	3.30	.000023	.000011

summer as compared with the night. It may also account for the increase of conductivity of the air required by Schuster¹ to explain the changes of the earth's magnetic field as brought about by movements of bodies of charged air.

Another set of readings will be given for the electroscope placed in the tower room of the fifth floor of the physics laboratory at the Johns Hopkins University. This room contains five windows, is thus well illuminated and is below the university's telescope. Except for a thin floor and the tin roof there is nothing to cut off the penetrating radiation from above.

Table IV. gives the rate of leak when the electroscope was sur-

¹Jour. de Phys., Dec., 1907.

rounded with a black wooden cap about .5 cm. thick, so as to prevent the entrance of any light. Table V. gives the rate of leak on the third floor of the physical laboratory, the room being surrounded by thick brick walls. Table VI. gives the rate of leak in a cave near Mechanicsburg. According to the work of Campbell and

TABLE III.

Electroscope in Tower Room.

I.	II.	III.	IV.
Local Mean Time.	Position of Gold Leaf.	Leak in Scale Divisions per Second.	III. Divided by the Sensibility.
Jan. 27, 1908.			
4 hrs. 30' P. M.	7.35		
Jan. 28, 1908.			
8 hrs. 40' A. M.	4.85	.000043	.000013
4 " 30' P. M.	3.63		
Jan. 29, 1908.			
8 hrs. 55' A. M.	2.30	.000022	.000015
Jan. 30, 1908.			
6 hrs. 5' P. M.	-.07		
Jan. 31, 1908.			
10 hrs. 10' A. M.	-.95	.000015	.000013
Feb. 5, 1908.			
8 hrs. 28' A. M.	2.13	.000021	.000016
2 " 44' P. M.	1.74	.000017	.000013
4 " 50' P. M.	1.60		
Feb. 6, 1908.			
8 hrs. 48' A. M.	.70	.000019	.000014
12 " 50' P. M.	.30	.000015	.000012
4 " 40' P. M.	.08	.000027	.000023
Feb. 7, 1908.			
10 hrs. 25' A. M.	-.82	.000016	.000013
5 " P. M.	4.78	.000014	.000012
Feb. 8, 1908.			
8 hrs. 30' A. M.	3.20	.000028	.000013
5 " 55' P. M.	2.00	.000035	.000025
Feb. 10, 1908.			
10 hrs. 15' A. M.	.58	.000018	.000016
4 " 50' P. M.	6.74		
Feb. 11, 1889.			
8 hrs. 45' A. M.	4.90	.000032	.000010

Wood, glass emits very little, if any, penetrating radiations. Any external radiation would therefore produce a greater relative change

TABLE IV.

Cap on Electroscope, Tower Room.

I.	II.	III.	IV.
Local Mean Time.	Position of Gold Leaf.	Leak in Scale Divisions per Second.	III. Divided by the Sensibility.
Feb. 26, 1908.			
6 hrs. 20' P. M.	7.05		
Feb. 27, 1908.			
8 hrs. 40' A. M.	4.93	.000041	.000012
5 " 17' P. M.	3.96	.000031	.000013
Feb. 28, 1908.			
9 hrs. 9' A. M.	2.74	.000021	.000012
5 " 35' A. M.	2.13	.000019	.000015
Feb. 29, 1908.			
10 hrs. 35' A. M.	1.18	.000015	.000012
4 " 77' P. M.	.86	.000014	.000012
Mar. 1, 1908.			
9 hrs. 10' A. M.	4.45		
3 " 5' P. M.	3.92	.000022	.000011

TABLE V.

Electroscope on Third Floor.

I.	II.	III.	IV.
Local Mean Time.	Position of Gold Leaf.	Leak in Scale Divisions Per Second.	III. Divided by the Sensibility.
Jan. 13, 1908.			
11 hrs. 44' A. M.	5.55		
1 " 29' P. M.	5.10	.000071	.000024
2 " 55' P. M.	4.75	.000068	.000023
5 " 2' P. M.	4.33	.000055	.000024
Jan. 14, 1908.			
8 hrs. 36' A. M.	2.50	.000033	.000026
10 " 12' A. M.	2.28	.000038	.000029

in the rate of leak in a glass vessel. Several electroscopes of glass were made. All metal parts were covered with sulphur and the outside of the electroscope was covered with aluminium foil. The following readings are typical.

Time.	Position of Gold Leaf.	Rate of Leak.
Nov. 25, 1907.		
4 hours, 51' P. M.	12.70	
Nov. 26.		
8 " 10' A. M.	11.95	.000013
5 " P. M.	11.05	.000038
Nov. 27.		
8 " 10' A. M.	10.35	.000013
4 " 42' P. M.	9.14	.000039
Nov. 28.		
8 " 30' A. M.	8.45	.000012

The above table shows that during the summer the rate of leak was much larger. During the nights of summer the rate of leak is very large as a rule, at least for the place observed. The readings for September 2 and 3 show a minimum at about 8 P. M. and a slight maximum about midnight.

If the penetrating radiation comes largely from the air, then the variations should be almost as great when all the electroscope is

TABLE VI.

Electroscope in Cave.

I.	II.	III.	IV.
Local Mean Time.	Position of Gold Leaf.	Leak in Scale Divisions per Second.	III. Divided by the Sensibility.
Sept. 28, 1907.			
8 hrs. 4' A. M.	6.70		
11 " 43' A. M.	5.90	.000061	.000017
7 " 41' P. M.	4.66	.000043	.000015
Sept. 29, 1907.			
8 hrs. 32' A. M.	3.70	.000021	.000010
5 " 3' A. M.	2.90	.000029	.000016
Dec. 24, 1907.			
3 hrs. 52' P. M.	7.00		
Dec. 25, 1907.			
8 hrs. 13' A. M.	5.08	.000033	.000010
12 hrs. 20' P. M.	4.64	.000030	.000011
4 " 7' P. M.	4.30	.000025	.000011
Dec. 26, 1907.			
8 hrs. 6' A. M.	3.05	.000022	.000011
12 " 30' P. M.	2.78	.000019	.000014
5 " 10' P. M.	2.47	.000018	.000013
Dec. 27, 1907.			
9 hrs. 15' A. M.	1.44	.000018	.000013
5 " 40' P. M.	1.00	.000014	.000012

screened except the top. This was done, the electroscope being placed on the roof of the physical laboratory.

TABLE VII.

Cap on, Electroscope on Roof.

I.	II.	III.	IV.
Local Mean Time.	Position of Gold Leaf.	Leak in Scale Divisions per Second.	III. Divided by the Sensibility.
March 10, 1908.			
5 hrs. 5' P. M.	3.97		
March 11, 1908.			
8 hrs. 15' A. M.	3.05	.000017	.000010
March 12, 1908.			
8 hrs. 5' A. M.	5.70	.000047	.000018
5 " 21' P. M.	3.83		
March 13, 1908.			
8 hrs. 40' A. M.	2.78	.000019	.000012
6 " 14' P. M.	2.12	.000019	.000015
March 14, 1908.			
8 hrs. 40' A. M.	1.40	.000014	.000011

These tables show that the rate of leak for the unscreened electroscope varies between wide limits but it is never less than the rate of leak for the screened electroscope. The variation is much less in Baltimore than in the country. The rate of leak in a cave is much less than the rate of leak observed on the surface and the variations are very much less. If the larger part of the external radiation comes from the ground, then in a cave the rate of leak should be twice as great as on the surface of the ground, but this is not so. The rate of leak at night in the physical laboratory is fairly constant compared with the leak during the day. The readings during the night in the country are much larger during the summer. The screening of all parts of the electroscope except the top and placing the electroscope thus screened on the roof of the physical laboratory did not decrease the variations very greatly.

IV. THE DIURNAL PERIOD OF THE RATE OF LEAK.

Some of the results obtained with the unscreened "sheet-iron" electroscope will now be given. This electroscope was used in the tower room. Readings were made with a micrometer microscope,

the micrometer being in the eyepiece. Both micrometer microscope and electroscope were kept fixed, so that only a small portion of the path of the gold leaf could be used. When the gold leaf passed out of the field of the microscope, the electroscope would be recharged. In the curves these intervals are represented by dotted lines. When lead screens were placed around the electroscope, it was found that the natural ionization in the instrument produced a constant rate of leak and therefore the fluctuations observed with the unscreened electroscope as given by the following curves were due to external causes. All the curves except Fig. 9 were taken in the tower of the physical laboratory. This latter was taken near Mechanicsburg, Pa. These and other curves show maxima at 9 A. M. and 10 P. M., marked minima at 7 A. M. and 6 P. M.¹ and a less marked one about noon. Wood and Campbell² find maxima at 9 A. M. and 10 P. M., minima at 2 P. M. and 4 A. M. McKeon³ finds maxima at about 10 A. M. and 11 P. M. and minima at 6 P. M. and 7 A. M.

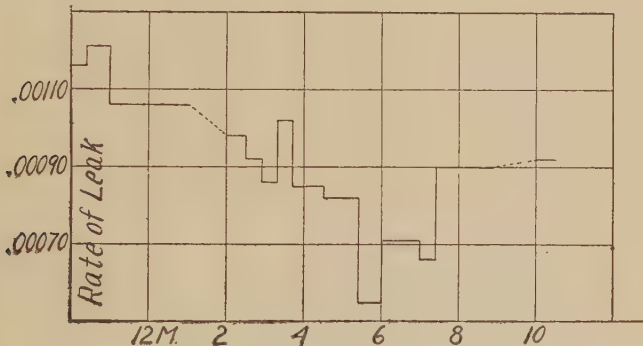


Fig. 4.

Description of Curves. — Fig. 4. Ionization curve for February 19, 1907, taken in the "tower room." Weather clear. Fig. 5. Ionization curve for February 26, 1907, taken in the "tower room." Weather clear and warm. The temperature variation in the room during the day was but 2° C. Mean barometer 76.60

¹ Science, July 12, 1907.² Phil. Mag., Feb., 1907.³ PHYS. REV., Nov., 1907.

cm. Sleet in evening about 8 P. M. Fig. 6. Ionization curve for February 25, 1907, taken in the "tower room." Weather clear. The day previous a snow eight inches deep had fallen and this still covered the ground. If the penetration radiation had

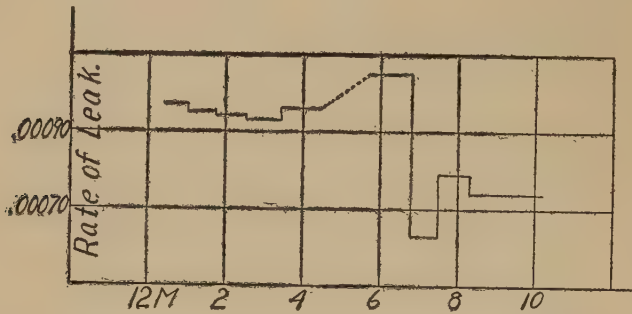


Fig. 5.

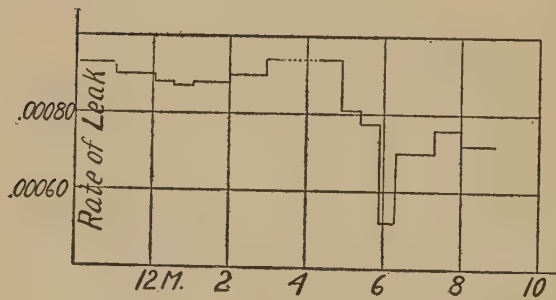


Fig. 6.

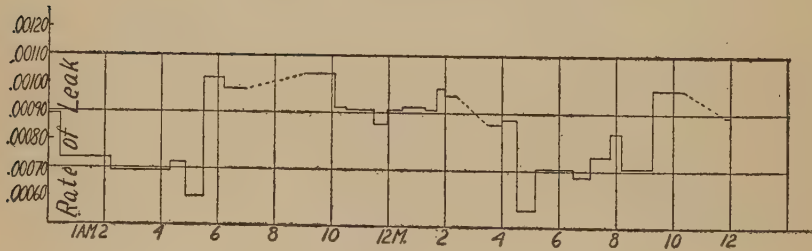


Fig. 7.

come from the ground the snow would probably have screened a considerable part of it. But this is not the case. Barometer 76.25 cm. In Fig. 5 it is seen that during the sleet the ionization is quite small. Fig. 7. Ionization curve for February 23, 24, 1907, for the "tower room." Weather clear and cold. Barometer 77.80

cm. Temperature range 11° to 15° C. Fig. 8. Ionization curve, March 9, 10, 1907, taken in the "tower room." At midnight it began to snow. The curve shows how the ionization has thereby been decreased. The barometer decreased gradually from 77.00 cm. at the beginning of the observations and dropped to 76.00 cm. at the end of the observations. The temperature varied

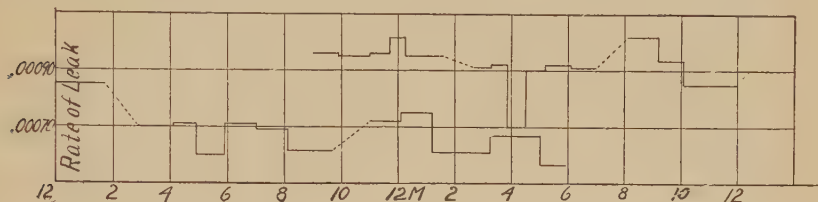


Fig. 8.

between 12° and 18° C. Fig. 9. Ionization curve taken December 26, 1907 near Mechanicsburg, Pa.

The rate of leak over a considerable part of the scale of the fixed microscope when the electroscope was screened was found for the "sheet-iron" electroscope. A calibration curve for this

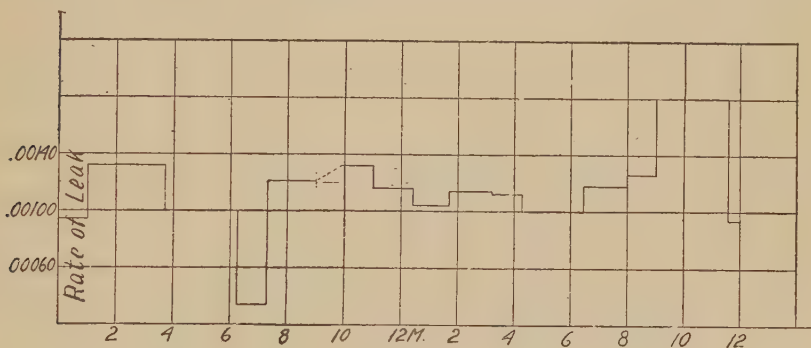


Fig. 9.

part of the scale was then drawn as for the aluminium electroscope. This calibration curve thus gave the relative sensibility of the different parts of the scale. The rate of leak over any part of the scale divided by the sensibility ought to be unity for the screened electroscope and greater than unity for the unscreened electroscope. This will be shown by the following figures.

I.	II.	III.	IV.
Local Mean Time.	Position of Gold Leaf.	Leak in Scale Divisions per Second.	III. Divided by the Sensibility.
April 8, 1907.			
8 hrs. 34' A. M.	10.814		
3 " 34' P. M.	18.403	.000334	1.095
8 " 55' P. M.	6.978		
April 9, 1907.			
8 hrs. 20' A. M.	19.890	.000318	1.092
April 10, 1907.			
10 hrs. 53' A. M.	11.896		
5 " 44' P. M.	19.900	.000324	1.062
May 1, 1907.			
11 hrs. 56' A. M.	.117		
10 " 58' P. M.	10.278	.000273	1.066
May 2, 1907.			
11 hrs. 55' A. M.	.112		
9 " 43' P. M.	11.483	.000301	1.153

The average for twenty one days for column IV. was 1.147. Now to show the great variation in the rate of leak the top part of the screen was removed. The following readings show that the

I.	II.	III.	IV.
Local Mean Time.	Position of Gold Leaf.	Leak in Scale Divisions per Second.	III. Divided by the Sensibility.
May 10, 1907.			
11 hrs. 57' A. M.	1.60		
3 " 14' P. M.	7.683	.000500	2.03
5 " 28' P. M.	.629		
10 " 53' P. M.	8.856	.000398	1.59
May 11, 1907.			
12 hrs.	1.889		
3 " 57' P. M.	10.070	.000690	2.65
May 13, 1907.			
1 hrs. 46' P. M.	-.548		
10 " 15' P. M.	7.310	.000270	1.11
May 14, 1907.			
10 hrs. 58' A. M.	.710		
7 " 50' P. M.	11.306	.000357	1.37
May 16, 1907.			
12 hrs. 54' P. M.	1.487		
6 " 50' P. M.	14.740	.000600	2.22
May 17, 1907.			
10 hrs. 56'	-.253		
5 " 45'	9.270	.000407	1.63

external radiation entering at the top of the electroscope was what produced the great variations in the rate of leak.

V. THE RATE OF LEAK DURING A SNOW OR RAIN.

The effect of a snow in decreasing the external radiation is shown very well by Fig. 8. Here it began to snow about midnight. Upon the scale given, .00049 is the rate of leak in scale divisions per second when the electroscope is screened. In Table IV., March 1, 1908, there was rain during the day. February 5, 1908, there was a snow. September 2, 1907, there was a thunderstorm during the afternoon. During the night of September 3 there also was rain. These data show that in these cases the penetrating radiation fell almost to zero value. This is to be expected since rain and snow are known to carry down radium A, B and C. On account of the quick recovery of the external radiation it seems very probable that the emanation remains in the air.

VI. THE ORIGIN OF THE PENETRATING RADIATION.

Since the penetrating radiation resembles the γ rays from radioactive substances it is very probable that it originates from radioactive substances. The problem then is to locate these radioactive substances. From the radium content of the various rocks as determined by both Strutt and Eve it appears that there is not enough radium in the ground to account for the penetrating radiation.¹ Taking a value of the radium content which is probably large, the γ radiation which this would be the source of, would produce less than one ion per c.c. per second. Cooke found the penetrating radiation to produce 4.5 ions per c.c. per second, McClennan 9 ions per c.c. per second, and for an electroscope with a cap the writer found that the penetrating produced 4 ions per c.c. per second when screened on the under side. Firstly, then, the radium content of the ground is not sufficient to produce a sufficiently powerful penetrating radiation. Secondly, a penetrating radiation coming from radioactive products in the earth should be constant in amount. The penetrating radiation varies considerably in value. Thirdly, during a rain or snow the penetrating radiation decreases very much

¹ Terr. Mag., Dec., 1907.

in value. Rain and snow carry radioactive products into the ground and increase the radioactive content of the ground, without increasing the penetrating radiation. Fourthly, screens placed about electrosopes on all sides except the top should absorb practically all the penetrating radiation from the earth. Experimentally, however, this is not found to be the case. Fifthly, the penetrating radiation in a cave should be larger than the penetrating radiation on the surface if this has its source in the ground. The writer has, however, found the penetrating radiation less in a cave. The conclusion is that under the conditions of investigation the larger part of the penetrating radiation did not come from the ground.

On the other hand a very simple method of explaining the above results is to suppose that the penetrating radiation comes largely from radioactive products in the air. Suppose that a considerable part comes from radium C which has been broken down from the emanation. Now it is known that most of the radioactive products carried down by rain or snow consist mostly of radium products.¹ During a heavy rain or snow most of the radium products would be carried down and so the penetrating radiation would be considerably decreased.

If the emanation remains in the air, then in a few hours after the snow or rain, the products radium A, B and C will soon be in equilibrium again, and the penetrating radiation will increase to its normal value. This has been noticed to occur in about two hours in one case. This theory would explain why the active deposit occurs in rain or snow even if the storm has been a long one, the active deposit being continually formed from the radium emanation. As the radium emanation has been shown by Elster and Geitel,² Ebert and Ewers³ and others to diffuse up through the ground, it is quite probable that the radium emanation in the air comes largely from the ground. The amount of emanation would then vary with the direction and strength of the wind. The air over large areas of low barometer would contain more emanation and this air would be carried about by cyclonic and anticyclonic storms.

¹ J. S. Allen, *PHYS. REV.*, p. 306, 1903; C. T. R. Wilson, *Proc. Camb. Phil. Soc.*, **11**, p. 428, 1902; J. Kaufmann, *Meteorologische Zeit.*, March, 1905; Costanzo and Negro, *Phys. Zeit.*, 7, pp. 350, 921, 1906.

² *Phys. Zeit.*, 3, p. 574, 1902.

³ *Phys. Zeit.*, 4, p. 162, 1902.

Recent determinations by Eve¹ of the content of the air of radium emanation do not bear out the above theory quantitatively, the emanation content being too small to account for the penetrating radiation. But at the same time the penetrating radiation may have been small. Eve² then suggests that the penetrating radiation may come from thorium products in the ground.

As the γ radiation from thorium would require 6.9 (10^6) times³ as much thorium in weight as radium, the amount of thorium necessary to produce the penetrating radiation would be quite large. It would be very interesting to make a thorium survey of various minerals and rocks. Recent work by Dadourian⁴ does not indicate a large thorium content in the ground.

It hardly seems possible to account for the variations of the penetrating radiation if this comes from radioactive products in the ground. This difficulty is especially pronounced in a city where all the rain water runs away immediately after its fall, it not being able to wash the active deposit down into the ground. In some localities, however, there may be enough radioactive material in the ground to explain the penetrating radiation.

The diurnal variations are much more difficult to explain. If the larger part of the penetrating radiation comes from the active deposit in the air, and this is probably largely condensed on the "large" ions of Langevin, then if these large ions were suddenly carried down to the ground there would be a minimum ionization. But how this could happen is not evident. If the "large" ions are numerous and the active deposit is attached to these, then the active deposit would be more difficult to draw out of the air by means of charged wires. If the active deposit was attached to the "small" ions in the air, then it would be more easily acquired by a charged wire. This may explain some of the variations in the amount of active deposit formed on charged wires.

According to the recent work of Cameron and Ramsay, helium is formed from the radium emanation when the latter is mixed with a gas, argon and neon, when the emanation is mixed with certain

¹ Phil. Mag., Dec., 1907.

² Nature, p. 486, March 26, 1908.

³ Am. Journ. of Science, Dec., 1906.

⁴ Am. Journ. of Science, Apr., 1908.

liquids. It might be possible that a part of the helium and argon in the atmosphere is formed in this way. If one knew the amount of radium emanation in the air, a calculation of the amount of helium formed could be made. If, then, helium is not accumulating in the atmosphere, this means that the amount of helium formed is equal to the amount which the earth's atmosphere loses to space.

VIII. CONCLUSION.

1. A form of electroscope with a curved electrode and earthed gold leaf is very convenient in working with comparatively large vessels.

2. The ionization in closed vessels investigated has been found to be constant when the vessels are surrounded with lead and iron screens. The rate of leak due to this ionization has been used to calibrate the electroscope.

3. The variation of the rate of leak of an unscreened electroscope is due to external radiations. Part of this external radiation is the so-called penetrating radiation.

4. The external radiation is greater during the summer.

5. The curved electrode electroscope has a double diurnal period in its rate of leak.

6. During a rain or snow the penetrating radiation decreases very considerably for the cases observed. In several instances the penetrating radiation has reached almost a zero value.

7. An electroscope open at the top but with thick screens on all sides and on the bottom, is subject to very considerable variations in its rate of leak. From this and other reasons it seems very probable that a considerable part of the penetrating radiation comes from radioactive products in the air.

8. Since the coefficient of absorption for air is small, the penetrating radiation from radioactive products in the air comes from large bodies of air at considerable distance from the place of observation. A study of this penetrating radiation at different places would indicate the origin and movements of radioactive matter in the air.

The writer's thanks are extended to Professor Ames for his help and kindness throughout the course of the investigation.

JOHNS HOPKINS UNIVERSITY,
April, 1908.

VITA.

William Walker Strong was born May 16, 1883, at Good Hope, Pa., his parents being William H. and Maria Garretson Strong. He received his early training at the Harrisburg Academy and the Mechanicsburg Normal and Classical School. He entered Dickinson College in the fall of 1901 and received the degree of Bachelor of Science in 1905. In the fall of 1905 he began graduate work at the Johns Hopkins University in physics, physical chemistry and mathematics. He held a university scholarship in 1906-07 and a fellowship in 1907-08.

In the progress of his graduate work courses were taken under Professors Ames, Wood, Whitehead, Bliss, Jones, Cohen, Doctors Barnes, Pfund and Anderson, and Mr. Jewell.

THE PHYSICAL REVIEW

A JOURNAL OF EXPERIMENTAL AND THEORETICAL PHYSICS

CONDUCTED

WITH THE CO-OPERATION OF THE

AMERICAN PHYSICAL SOCIETY

BY

EDWARD L. NICHOLS

ERNEST MERRITT, AND FREDERICK BEDELL

Two volumes of THE PHYSICAL REVIEW are published annually, these volumes beginning in July and January, respectively, and containing six numbers each. The price of subscription is two dollars and fifty cents a volume (five dollars a year), or fifty cents a single number, seventy-five cents double number. Subscriptions should be sent to the publishers, THE MACMILLAN COMPANY, 41 *North Queen Street, Lancaster, Pa.*, or 66 *Fifth Avenue, New York*; Messrs. MACMILLAN & CO., LTD., *London*; or to Messrs. MAYER AND MUELLER, *Berlin*.

THE PHYSICAL REVIEW beginning with Vol. XVI. (January-June, 1903) is conducted with the co-operation of the AMERICAN PHYSICAL SOCIETY. The separate publication of the BULLETIN of the Society has been discontinued and its Proceedings are hereafter to be published regularly in the REVIEW.

Previous to Volume V. (July-December, 1897) THE PHYSICAL REVIEW was published in annual volumes, each containing six bi-monthly numbers, beginning with the July-August number, 1893. These may be obtained from the publishers at the former subscription price, three dollars per volume.

Correspondence relating to contributions should be addressed to the editors at *Ithaca, New York*.

Manuscript intended for publication in THE PHYSICAL REVIEW must be communicated by the author; when publication in other journals is contemplated, notice to that effect should be given.

The authors of original articles published in the REVIEW will receive one hundred separate copies in covers, for which no charge will be made; additional copies, when ordered in advance, may be obtained at prices depending upon the length of the article, etc. A schedule of prices may be obtained from the editors.

THE MACMILLAN COMPANY

Entered at the post-office, at Lancaster, Pa., as second-class mail matter.

